PALATABILITY AND TENDERNESS EVALUATION OF BEEF TOP SIRLOIN STEAKS USING VARIOUS AGING TIMES AND STORAGE CONDITIONS

A Thesis

by

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ABSTRACT

The objectives of this study were to 1) assess whether extended aging periods for the top sirloin were necessary to improve consumer perception of tenderness, and 2) evaluate the impact of freezing of top sirloin butts during the subprimal storage period to see if steak tenderness would be enhanced, or if there were any discernable differences in palatability or tenderness. Paired USDA Choice top sirloin butts (*n* = 40) were collected from 20 carcasses and divided among 2 treatment groups: 1) 14- versus 35-day refrigerated aging (all subprimals stored ~ -1 °C for the assigned number of days), and 2) refrigerated aging (aged under refrigeration for 35 days before cutting into steaks) versus frozen aging (aged under refrigeration for 14 days, frozen for 14 days, and then placed back in refrigeration for 7 days before cutting into steaks). Consumer sensory testing was conducted to evaluate if consumers could discern a difference in tenderness, flavor, juiciness, and overall likeability between treatments. Steaks also were subjected to Warner-Bratzler Shear (WBS) force for objective tenderness evaluation. Comparisons for both objective and subjective tenderness evaluations showed no significant treatment differences. Results of the 14- versus 35-day refrigerated aging treatments indicate that the top sirloin butt did not require extending-aging periods to increase tenderness. The lack of differences in the refrigerated versus frozen treatments reflect no detrimental consumer perceptions in the comparison of fresh versus frozen sirloin steaks. Tenderness levels of top sirloin steaks were acceptable regardless of treatment, indicating that purveyors have options and flexibility in inventory control for top sirloin butts.

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NOMENCLATURE

ATP	Adenosine triphosphate
^{o}C	degrees Celsius
cm	centimeter
^{o}F	degrees Fahrenheit
g	gram
h	hours
IMPS	Institutional Meat Purchasing Specifications
kg	kilogram
lb	pound
M.	muscle
min	minute
mm	millimeter
N	Newtons
NBQA	National Beef Quality Audit
NBTS	National Beef Tenderness Survey
oz	ounce
USDA	United States Department of Agriculture
WBS	Warner-Bratzler Shear
WTP	Willingness to pay

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1. INTRODUCTION

The beef top sirloin steak is an important foodservice cut and is often served at a lower cost than other foodservice steaks. Yet, when the cost-conscious consumer is presented with a sirloin, this cut often does not deliver a desirable eating experience, especially when compared to that of other popular middle-meat cuts. The sirloin is a cut that often underperforms in overall eating quality, largely due to inherent variabilities in tenderness (Wheeler, Miller, Savell, & Cross, 1990). Wheeler et al. (1990) stated that the increasing demand for higher-quality beef to enter branded programs and larger consumer markets has subsequently increased demand for higher quality steaks that are consistent in their attributes. It is interesting to note that the large percentage of branded programs, such as Certified Angus Beef, do not include a process that would affect tenderness, such as an extended aging period (Koohmaraie & Geesink, 2006). Since the top sirloin was listed as the 5th and 6th most popular cut for the first and second quarters of 2017, respectively, it is important to consider satisfying consumer demand for higher quality beef (NCBA, 2018). Meeting consumer expectations is important from an industry perspective, as negatively-perceived eating experiences may lead to decreased beef consumption.

Factors contributing to beef palatability are tenderness, juiciness, and flavor (Savell, 2017c). Historically, the sirloin has had lower tenderness values, which is important to consider since consumers view tenderness as the most important organoleptic characteristic of meat (Koohmaraie, 1994). In a blind panel conducted by Lusk, Fox, Schroeder, Mintert, and Koohmaraie (1999), a larger percentage of consumers preferred tender steaks over steaks that were tough, and as stated by Boleman et al. (1997), consumers are more willing to pay premiums for beef that is “guaranteed tender.” Johnson et al. (2016) reported differences in willingness-to-pay (WTP) by consumers of tender sirloins, with WTP ranging from $1.41/kg in a non-tasting panel to $4.83/kg premium after consumers tasted the meat. The non-tasting group was selected to represent consumers who make information-based product selections in retail settings, not decisions based on eating experiences (Johnson et al., 2016). Furthermore, Johnson et al. (2016) reported that consumers who did not taste the sirloins in their study were likely to not care about quality grade or tenderness, as opposed to those who tasted the meat and were likely to care more. Interestingly, in a similar study by Feuz, Umberger, Calkins, and Sitz (2004), it was found that consumers were more inclined to pay a premium for more tender steaks, regardless of the quality grade, and that the consumer’s WTP was not affected by quality grade. Johnson et al. (2016) suggested that consumer’s WTP based on quality grade descriptors found in the marketplace may indicate a lack of knowledge among consumers regarding the subject and the nomenclature/meaning of quality grade labels. Their research suggested that a transition towards more descriptive terminology such as “tender” or “juicy” may be more effective than labeling with only a quality grade (Johnson et al., 2016). This should be of significant consideration to the beef industry, especially since the current quality grade standards have no indication of/nor are they directly affected by meat tenderness, only carcass maturity and marbling in the ribeye (USDA, 2016).

In the 2016 National Beef Quality Audit (NBQA), all steer and heifer industry sectors, excluding packers, ranked eating satisfaction as the second most important factor to beef production and the beef industry, with tenderness being a main descriptor (Hasty et al., 2017). Packers did not include eating satisfaction as a must have, yet 55% of packers were willing to pay a premium of 10% for beef that would be guaranteed to meet consumers' eating expectations (Hasty et al., 2017). These data are important when viewing the overall snapshots of beef tenderness captured with the National Beef Tenderness Surveys (NBTS). Morgan et al. (1991) identified top sirloin steaks to be the toughest cut from the rib and loin when reporting Warner-Bratzler shear force (WBS) values. Historically, NBTS have reported the top sirloin steak to have lower tenderness values in both WBS and consumer ratings when compared to other cuts from the rib and loin (Brooks et al., 2000; Guelker et al., 2013; Voges et al., 2007). Voges et al. (2007) reported foodservice top sirloin steaks to have the lowest percentage of "tender" cuts, and the highest percentage of "tough" cuts when WBS values were separated into tenderness categories outlined by Belew, Brooks, McKenna, and Savell (2003). The 2010 NBTS reported the foodservice top sirloin steak to have the highest percentage of cuts across all tenderness categories, indicating a greater variability (Guelker et al., 2013). The stratification of 2015/2016 NBTS cuts across tenderness categories produced interesting results, in that foodservice sirloin steaks had higher percentages than the ribeye in the "very tender," "tender," and "intermediate" categories, and a lower percentage in the "tough" category (Martinez et al., 2017). Given that shear-force values are an indication of tenderness, these studies are representative of the short-comings and variability of the sirloin’s palatability.

2. LITERATURE REVIEW

2.1. Meat tenderness

There are many factors that can affect meat tenderness, including muscle composition, aging period, and aging conditions. Regarding muscle composition in a more specific context are the actomyosin, background, and bulk density effects. The actomyosin effect is related to the contractile condition of the sarcomeres and proteins within the muscle fibers (Calkins & Sullivan, 2007). The sarcomeres are the smallest contractile unit within the muscle and include the myofibrillar proteins actin and myosin. During both contraction and rigor mortis, actin and myosin bond to form actomyosin, also known as the rigor bond (Calkins & Sullivan, 2007). When these bonds form in the absence of ATP, they have a "locking" effect on the overlap of the actin and myosin filaments postmortem, shortening the sarcomere. The final length of the sarcomere can have effects on tenderness, as outlined by Marsh and Leet (1966). Rhee, Wheeler, Shackelford, and Koohmaraie (2004) reported the *M. gluteus medius* (GM) to have an average sarcomere length of 1.66 µm, the lowest of all cuts in this study. Muscles with shorter sarcomeres, such as the GM, tend to be less tender than those with longer sarcomeres (Harris, Miller, Savell, Cross, & Ringer, 1992). Sarcomere length also can be affected by location of the muscle within the carcass and the mechanism by which a carcass is hung. Carcasses hung vertically by the Achilles tendon of the hind limb have greater contraction of the GM muscles, hence having shorter sarcomeres (Herring, Cassens, & Briskey, 1965). In a study examining various carcass suspension techniques, Herring et al. (1965) reported an increase in WBS force for GM when the muscle was shortened by vertical suspension.

The background effect relates to the concentration of connective tissue within a muscle. Connective tissue in muscle is usually higher in muscles used for locomotion, or those found in the pelvic and thoracic limbs (Savell, 2017b). Mainly composed of the protein collagen, connective tissue can play a role in muscle tenderness in two ways: (1) by the amount of connective tissue present, and (2) the degree of solubility of the connective tissue present (Calkins & Sullivan, 2007). Cross, Carpenter, and Smith (1973) discovered that it is not necessarily the total concentration of collagen and elastin in the muscle that has the greatest effect on tenderness, but rather the percent soluble collagen. Harris et al. (1992) found that tenderness differences and consistency in top sirloin steaks was due, in large part, to higher amounts of collagen in combination with myofibrillar factors. This is not surprising with the GM, or top sirloin, as it is a locomotive muscle and functions to extend the hip joint and adduct the rear limb, according to the Bovine Myology website (Jones et al., 2004).

Finally, the bulk density or lubrication effect is thought to be caused by the fat or marbling within a muscle. Marbling is the fat deposited within the perimyseal layer of the muscle, also known as intramuscular fat (Warner, Greenwood, Pethick, & Ferguson, 2010). The term marbling is used to describe the visual score of intramuscular fat, and is subjectively measured to help assess and determine USDA quality grades (Warner et al., 2010). With regard to the bulk density effect, it is thought that the fat located in the perimysium of the muscle essentially lubricates the fibers with lipid, and that the dilution of the protein matrix with increased lipid also lowers the bulk density by decreasing the mass per unit of volume, essentially reducing the force needed to cut the meat (Smith & Carpenter, 1974). As the top sirloin is known as one of the leaner, not highly marbled muscles, it is not thought that this theory has a large effect on tenderness or palatability. More emphasis is put on the actomyosin and background effects when studying the sirloin because of its physiological characteristics. As the sirloin is often found to possess shorter sarcomeres and increased amounts of collagen, methods of enhancing tenderness that focus on alteration of the muscle fiber and connective tissue have been of great interest.

2.2. Aging meat

Subprimals such as the sirloin are often blade tenderized to maximize quality and tenderness, but with the inherent food safety risks associated with this process, there is opportunity to explore other less invasive postmortem tenderization methods. Extended aging periods have been postulated as an alternative method to increase postmortem tenderness. Limited research in variation of aging periods and effects on sirloin palatability leads to the possibility that certain aging lengths may benefit overall sirloin quality. Yet, the reported extensive lengths of time required for tenderness changes in sirloin steaks could have undesirable effects on eating quality, including off-flavor and soft texture (Colle et al., 2015; Harris et al., 1992).

As outlined by Gruber et al. (2006), it is known that postmortem aging of beef increases tenderness. Smith, Culp, and Carpenter (1978) stated this increase in tenderness to be attributed to endogenous enzymes in the muscle, loss of tensile strength in the myofibril, and shortening of the muscle fibers. There are three simple principles when considering ways to enhance meat tenderness: 1) cause sarcomeres to be longer, 2) disrupt the integrity of the myofibrils, and 3) disrupt the integrity of the connective tissue (Savell, 2017a). Postmortem proteolytic systems alter muscle ultrastructure and integrity of the myofibril, primarily at the Z-line by affecting the cytoskeletal proteins titin, nebulin, and desmin (Koohmaraie, 1994).

Cytoskeletal proteins are important in upholding the structural framework of muscle fibers, and each of these proteins in some way organize and uphold both skeletal muscle cells and the contractile myofibrils (Robson et al., 1997). The exact systems that coordinate enzymatic proteolysis postmortem are still not completely understood. Of the major proteins that comprise muscle, postmortem enzyme systems do not largely affect the proteins actin and myosin. It is known that the larger proteins titin and nebulin undergo proteolysis early postmortem, and have been identified as preferred substrates for the calpain system (Robson et al., 1997). These two large proteins run parallel with the long axis of the sarcomere and by doing so help make up the overall structural framework of the myofibril (Robson et al., 1997). Titin is the only protein to run the entire length of the sarcomere and works to scaffold and align the sarcomeres. With these functions, postmortem proteolysis of titin largely impacts the ultrastructure of the muscle (Robson et al., 1997). According to Robson et al. (1997), titin is almost completely degraded by 3 days postmortem, paralleling measurements of meat tenderness.

Nebulin is another large, skeletal protein that assists in organizing thin filaments during formation, and later continues to function in the same facet in mature myofibrils (Robson et al., 1997). Because nebulin works as a framework for thin filament formation, as well as serving as an anchor to the Z-line for thin filaments, proteolytic degradation of this protein can largely affect stability of the muscle fiber. Similar to titin, degradation of nebulin occurs very early postmortem at a very rapid rate and is very highly correlated to tenderness measurements (Robson et al., 1997).

Furthermore, the protein desmin plays an important role in intermediate filaments by anchoring myofibrils to the sarcolemma, though the rate of degradation is slower than that of titin or nebulin (Robson, 1995). Though the degradation rate of desmin is slower, it is directly related to tenderness measurements (Huff-Lonergan, Mitsuhashi, Parrish, & Robson, 1996; Robson et al., 1997). Huff-Lonergan et al. (1996) identified that in "tender" samples of bovine muscles, desmin degradation occurred three days postmortem, whereas "tougher" samples showed no degradation until seven to fourteen days.

Differing proteolytic systems have been thought to play roles in postmortem proteolysis, which include cathepsins, multi-catalytic proteinase complex (MCP), and calpains (Koohmaraie, 1994). In a review by Koohmaraie (1994), it was stated that when comparing the systems, there is evidence suggesting that it is not the lysosomal cathepsins or MCP that play a role in postmortem proteolysis, but rather that the calpains are the primary proteolytic system utilized in postmortem aging of meat. The calpain system in skeletal muscle consists of at least 3 proteases of the calcium-dependent proteinases: calpain I, calpain II, and calpain III, as well as calpastatin, which is the inhibitor of calpain (Nowak, 2011). The activity of these proteases depends primarily on the muscle pH and concentration of calcium ions within the fiber, but temperature can also have an effect (Goll, Thompson, Li, Wei, & Cong, 2003; Steen, Claeys, Uytterhaegen, De Smet, & Demeyer, 1997). Calpains have the most effect at the Z-line, working to degrade cytoskeletal proteins titin, desmin, and nebulin, as well as tropomyosin, troponin T, and troponin I (Nowak, 2011).

As these enzymatic systems occur over a period of time, the total time subprimals spend in an aging period can have an effect on meat tenderness. The 2016/2016 NBTS reported that subprimal aging times at retail averaged 25.9 days, ranging from 6 to 102 days (Martinez et al., 2017). This is in contrast to the previous NBTS studies, which reported shorter post-fabrication aging periods at the retail level. Guelker et al. (2013) reported an average time of 20.5 days, compared to Voges et al. (2007) and Brooks et al. (2000) who reported averages of 22.6 and 19.0 days, respectively. This trend of increased aging times for beef could potentially lead to increased opportunity for proteolysis to further occur.

2.3. Freezing meat

In addition to postmortem proteolysis, freezing of meat has been researched as a way to improve tenderness of certain cuts. Incorporating a freezing/thawing step during an aging period could benefit purveyors and foodservice establishments due to the simplicity of the process. Wheeler et al. (1990) stated that utilizing frozen steaks rather than chilled steaks offers retailers, foodservice, and purveyors the advantages of increased storage time, greater flexibility in inventory, and greater product control. If there are innate tenderness benefits associated with freeze/thaw aging periods, this could be beneficial as well. Freezing meat has the potential provide a method to enhance tenderness and extend shelf life. Various research has produced differing results as to if freezing meat improves or hinders tenderness, especially from a consumer sensory perspective. It is known that freezing meat is advantageous in that it preserves product longer than fresh storage, yet freezing also increases drip loss and causes ultrastructural changes in the muscle fiber (Hergenreder et al., 2012; Hiner, Madsen, & Hankins, 1945; Leygonie, Britz, & Hoffman, 2012; Shanks, Wulf, & Maddock, 2002). In work conducted by Grayson, King, Shackelford, Koohmaraie, and Wheeler (2014), it was reported that there was an increase in tenderness from a freeze/thaw treatment. The effects seen in this study were likely due to structural damage from ice crystal formation during the thaw, in addition to increased proteolysis from postmortem enzyme systems (Grayson et al., 2014).

As meat is approximately 70 to 75% water, with most water being located within the muscle fibers, manipulation of this water through freezing can alter the ultrastructure of the fiber (Hiner et al., 1945). Bevilacqua, Zaritzky, and Calvelo (1979) noted the complexity of freezing meat due to the components of the muscle and water being located both inside and outside the muscle fibers. The improvement of tenderness through freezing is thought to occur because of structural damage due to ice formation within the muscle structure, in addition to affecting the rate of aging (Leygonie et al., 2012). The ice causing these disruptions can vary depending on many factors including the time and temperature meat is frozen.

The rate at which meat is frozen is very important when considering formation of ice crystals. As water freezes, it crystallizes the pure water and pushes out the soluble/insoluble substances suspended within (Hiner et al., 1945). The formation of compartments of ice between muscle fibers damage the structure of the myofibril and lead to fragmentation, resulting in tenderization (Leygonie et al., 2012). Very rapid rates of freezing lead to small ice crystal formation and little structural damage, while slower rates of freezing lead to larger crystal formation and increased damage to the fiber (Petrovic, Grujic, & Petrovic, 1993). At higher temperatures (-8°C), ice crystals form between muscle fibers while pushing the semi-dehydrated muscle fibers into irregular formations (Hiner et al., 1945). As rate and degrees of freezing increase under decreasing temperatures, smaller ice crystals form while the proportion of ice within the fibers becomes large enough to rupture the fiber (Hiner et al., 1945).

Furthermore, the exact proteolytic enzyme systems involved in frozen aging of meat and their function are not yet fully understood. Dransfield (1996) reported that μ-calpain is not affected by freezing, but loses some activity after thawing, with this inactivity increasing with longer frozen aging periods. Interestingly, the activity of m-calpain was not affected at all by freezing (Dransfield, 1996). Conversely, calpastatin, the inhibitor of calpain, also has been shown to be unstable when frozen, with activity of calpastatin decreasing over time under freezing conditions (Koohmaraie, 1990). The instability of calpastatin during freezing has been attributed to increased calpain activity and enhancement of tenderness. Crouse and Koohmaraie (1990) proposed the idea that freezing meat decreases the activity of inhibition of the calcium-dependent proteases, speculating that freezing meat before aging could increase postmortem proteolysis after thawing. The limited research on freezing and proteolytic systems does not identify enzymatic activity as a likely candidate in the alteration of meat tenderness when frozen.

As the production of beef continues to increase, it is important to the industry that as beef quantities increase, quality and tenderness are not sacrificed. As previously discussed, aging of meat is an important step in ensuring tenderness of beef products sold to consumers. However, long postmortem aging periods can create problems in merchandising and storage of meat due to larger volumes of beef being produced (Davey, Kuttel, & Gilbert, 1967). Simultaneously, the use of freezing beef to help alleviate this increased production constraint on beef supply has been speculated to have negative impacts on the final meat quality available at the consumer-level. This study was conducted to determine if extended aging periods were necessary for a high-demand cut such as the sirloin, and to see if extended aging time improved tenderness of the muscle from the perception of consumers. This study also aimed to evaluate the use of freezing subprimals as a method to enhance tenderization and to determine if consumer sensory panelists could identify differences between fresh versus frozen steaks.

3. MATERIALS AND METHODS

3.1. Product collection

Paired USDA Choice beef loin, top sirloin butt, semi center-cut, boneless subprimals (*n* = 40 total pieces), similar to USDA (2014) Institutional Meat Purchasing Specifications (IMPS) 184A (primarily consisting of the *M. gluteus medius*, with the *M. gluteus profundus* and *M. gluteus accessorius* removed) were collected from a major beef supplier. Subprimals were obtained from carcasses selected using the following criteria: 1) under 30 mo of age, 2) no dairy or *Bos indicus* influence, 3) overall acceptable quality of exposed *M. longissimus thoracis* area at the 12^{th} rib (no blood splash, discoloration, or exudation), and 4) carcass weights ranging from 295 to 459 kg (mean = 326.8 kg).

After fabrication, subprimals were labeled, vacuum packaged individually, boxed, and shipped under refrigeration to a collaborating beef purveyor. Paired subprimals were divided equally among two trials: 1) refrigerated versus frozen aging and 2) 14 versus 35-d refrigerated aging. For all trials, aging periods began the day of subprimal fabrication, which occurred two days postmortem.

3.2. Trial 1: Refrigerated versus frozen aging

Ten paired top sirloin butts (*n* = 20 total pieces) were used. All products were aged initially under refrigeration (~ -1 °C) for 14 d. From each pair, the left top sirloin butt was frozen (~ -20 °C) for 14 d, returned to refrigeration (~ -1 °C) for 7 d, achieving an aging period of 35 d. Right top sirloin butts remained under refrigeration for the entire 35-d aging period, serving as the control.

3.3. Trial 2: 14- versus 35-day aging

Ten paired top sirloin butts (*n* = 20 total pieces) were used. Left top sirloin butts of each pair were aged under refrigeration (~ -1 °C) for 14 d before cutting into steaks. Right top sirloin butts from the pair were aged under refrigeration (~ -1 °C) for 35 d before cutting into steaks.

3.4. Subprimal fabrication

All subprimals then were cut perpendicular to muscle fibers into five portions (2.5-cm thick) using a Grasselli (NSL 800, Albinea, Italy) slicer. Portions were identified as 1, 2, 3, 4, and 5, cranial to caudal, with only Portions 2 and 3 used for this project. Three steaks (~170 g) were hand cut from each of these two portions for a total of six steaks. One steak was used for Warner-Bratzler Shear (WBS) force, four steaks were used for consumer sensory panels, and one steak was held in reserve.

3.5. Packaging

Steaks were labeled and vacuum packaged individually with a rollstock machine (Multivac R150; Kansas City, MO) using Sealed Air, Food Care Division (Charlotte, NC) Item No. T7230B 3.0 mil top web with an Oxygen Transmission Rate (OTR) 4 [cc/ m^2/ day @ 23°C, 0% R.H] and Item No. T7045B 4.5 mil bottom web with an OTR of 3 [cc/ m^2/ day @ 23°C, 0% R.H]. Steaks then were boxed and placed into plastic insulated containers with refrigerated materials and transported to Texas A&M University (College Station, TX). Upon arrival, steaks for Trial 1 were stored under refrigerated conditions (~ 0 °C) until subsequent analyses; steaks for Trial 2 were flash frozen (-40 °C), then stored frozen (~ -23 °C) and later thawed for testing.

3.6. Cooking of steaks

Steaks for consumer sensory analysis and WBS force were cooked in the same manner. For Trial 1, cooking was completed within three days of steak arrival at Texas A&M University. For Trial 2, frozen steaks were thawed under refrigerated conditions (~ 0 °C) for 48 h before cooking. All steaks were cooked on a Star International commercial flat-top grill (Max Model 536TGF, St. Louis, MO). The grill was preheated to 176°C ± 2 °C, with internal steak temperatures monitored using thermocouple readers (Model HH506A; Omega Engineering, Stanford, CT) and 0.02-cm diameter copper-constantan Type-T thermocouple wires (Omega Engineering) inserted into the geometric center of each steak. Steaks were cooked to 35 °C, flipped, and cooked to a final endpoint temperature of 70 °C. Raw out-of-package weight, grill temperature, % cook loss, final internal temperature, and final cook weight were collected for each steak. Steaks assigned to consumer panels were kept warm in an Alto-Shaam oven set at 60 °C (Model 100-TH, Alto-Shaam Inc., Menomnee Falls, WI) for no more than 20 min. Steaks for WBS force were placed on plastic trays in a manner to avoid any overlapping, covered with plastic wrap, and stored in a cooler (2 to 4 °C) for 12 to 18 h before analysis.

3.7. Consumer sensory analysis

Consumer panelists (*n* = minimum of 80 per trial) were recruited from the Bryan/College Station area using an existing consumer database. Upon arrival at the sensory facility, panelists completed a demographic survey and were provided with a brief orientation of sample evaluation. Panelists were divided into 5 groups, each consisting of 4 panelists. Each group received two matched pairs for sampling, served in a double-blind and random order assigned by a random number generator (Microsoft Excel; Microsoft Corp., Redmond WA) and checked for duplicates. Procedures were approved by the Texas A&M Institutional Review Board for Use of Humans in Research (Protocol No. IRB2016-0227M).

Steaks were cut into fourths. Each sample (one-fourth of a steak) was presented on a plastic plate labeled with a random three-digit ID number of the corresponding steak, along with a metal steak knife and a plastic fork, to simulate a typical eating experience for the panelists. Panelists were provided with Nabisco Unsalted Tops Premium Saltine Crackers (Kraft Foods Global, Inc., East Hanover, NJ) and double-distilled, deionized water to use as palate cleansers between each sample. Serving order was randomized for each group to eliminate first-order bias. Samples were served through individual breadbox-style sensory booths equipped with red theater lighting to prevent panelist bias for degree of doneness. Panelists evaluated samples using 9-point scales (1 = dislike extremely; 9 = like extremely) for overall liking, flavor liking, tenderness liking, and juiciness liking.

3.8. Warner-Bratzler shear force analysis

Following storage, steaks were allowed to equilibrate at room temperature before being trimmed of visible connective tissue to expose muscle fiber orientation. Using a hand-held coring device, six 1.3-cm cores were removed from each GM. Connective tissue and excess fat were avoided when coring as much as possible. Cores were removed parallel to the muscle fibers and sheared once, perpendicular to the muscle fibers, on a United Testing machine (United SSTM-500, Huntington Beach, CA) at a cross head speed of 200 mm/min using a 10-kg load cell, and a 1.02-cm thick V-shape blade with a 60° angle and a half-round peak. The peak force (kg) needed to shear each core was recorded, converted to Newtons (N), and the mean peak shear force of the cores was used for statistical analysis. The equipment was calibrated before the start of data collection, and calibration was checked after shearing every 60 cores.

3.9. Statistical analysis

Microsoft Excel (Microsoft Corporation, Redmond, WA) was used to calculate frequencies for consumer panelists' demographics. Trial data were analyzed separately with paired t-tests, using the matched pairs function of JMP (Version 12, SAS Institute, Inc., Cary, NC), at an alpha of 5%.

4. RESULTS AND DISCUSSION

4.1. Refrigerated versus frozen aging

Table 1 contains the weights, steak temperatures, cook loss, grill temperatures, and cook durations for all sensory and WBS force steaks that were cut from subprimals assigned to the refrigerated or frozen treatments. There were no differences in sensory panel ratings or WBS force values ($P > 0.05$) between the refrigerated versus frozen aging treatments (Table 2). The average WBS force values for steaks from both refrigerated and frozen treatments were within the “very tender” category (Belew et al., 2003).

Table 1. Paired t-tests for weights, steak temperatures, cook loss, grill temperature, and cook duration of sensory and Warner-Bratzler shear force steaks from subprimals that were refrigerated versus frozen during aging.

Treatment[a]	*n*[b]	Raw weight (g)	Raw internal temperature (°C)	Cooked weight (g)	Cooked internal temperature (°C)	Cook loss (%)	Grill surface temperature (°C)	Cook duration (min)
Refrigerated	10	179.9	12.0	137.0	70.2	23.8	177.2	20.3
Frozen	10	170.0	12.4	128.7	70.0	24.4	176.8	17.6
SE		3.14	0.16	2.73	0.08	0.59	0.33	0.60
Prob > t		0.0059	0.9678	0.0073	0.0436	0.8081	0.8525	0.9993

[a] Treatment: Refrigerated = top sirloin butts were aged under refrigeration for 35 days before cutting into steaks; Frozen = top sirloin butts were aged under refrigeration for 14 days, frozen for 14 days, and then placed back in refrigeration for 7 days before cutting into steaks.
[b] Number of subprimals evaluated.

Table 2. Paired t-tests for sensory panel ratings and Warner-Bratzler shear force values for steaks from subprimals that were refrigerated versus frozen during aging.

Treatment[a]	*n*[b]	Sensory panel ratings[c] Overall like/dislike	Tenderness like/dislike	Flavor like/dislike	Juiciness like/dislike	Warner-Bratzler shear force (N)
Refrigerated	10	6.3	6.0	6.4	5.8	26.7
Frozen	10	6.1	5.8	6.2	6.1	30.7
SE		0.14	0.21	0.11	0.26	1.97
Prob > t		0.0946	0.3017	0.1005	0.2870	0.0733

[a] Treatment: Refrigerated = top sirloin butts were aged under refrigeration for 35 days before cutting into steaks; Frozen = top sirloin butts were aged under refrigeration for 14 days, frozen for 14 days, and then placed back in refrigeration for 7 days before cutting into steaks.
[b] Number of subprimals per treatment.
[c] Sensory panel ratings: 9 = like extremely; 1 = dislike extremely.

The use of freezing as a method to enhance tenderness and extend shelf life has long been a topic of interest in industry. It is known that freezing meat is advantageous in that it preserves product longer than fresh storage; however, freezing also increases drip loss and causes ultrastructural changes in the muscle fiber (Lagerstedt, Enfalt, Johansson, & Lundstrom, 2008; Wheeler et al., 1990). These changes are caused by the freezing and thawing processes, which alter the state of water within the muscle by creating compartments of ice between the muscle fibers (Leygonie et al., 2012). These compartments of water can form large, extracellular ice crystals, which can damage the structure of the myofibril and lead to fragmentation, resulting in tenderization (Leygonie et al., 2012). As previously stated, the temperature and rate at which meat is frozen can determine the size of ice crystals formed, and ultimately the degree of fiber disruption.

Research conducted observing the effects of freezing on meat quality has produced varying results in relation to tenderness (Grayson et al., 2014; Hergenreder et al., 2012; Hiner et al., 1945; Howard et al., 2013; Shanks et al., 2002; Wheeler et al., 1990). Works by Grayson et al. (2014), Hiner et al. (1945), and Shanks et al. (2002) support the theory that freezing and thawing of meat improves tenderness, whereas reports by Howard et al. (2013) and Wheeler et al. (1990) conversely do not. Shanks et al. (2002) found that across 9 postmortem aging periods, WBS force values were lower in frozen beef *M. longissimus* steaks than fresh steaks. Interestingly, Hergenreder et al. (2012) reported that across three different frozen treatments, WBS force values for sirloins were not different. The differing outcomes of these studies could be due to various factors including grade, aging conditions, the unique physiology of the muscle, and aspects of experimental design.

When considering the impact of freezing on consumer perception, Grayson et al. (2014) found that when top loin and eye of round steaks were aged for various periods, frozen, and then thawed, there were enough improvements in tenderness to warrant concern that steaks destined for research sensory analyses could be impacted by the freezing process. It is important to note that this research treatment was done on steaks, and not individual subprimals like the current study. Lagerstedt et al. (2008) found that sensory attributes of beef *M. longissimus* samples were altered by freezing, reporting lower shear force values for frozen versus chilled samples at 14 days of aging. Conversely, this study showed no differences in consumer perception of chilled meat compared to that which had been frozen, while trained sensory panel results showed the opposite (Lagerstedt et al., 2008).

In the current study, it was not known if freezing and thawing of the top sirloin subprimal would provide the same tenderness benefits as those seen with individual steaks (Grayson et al., 2014). We found that freezing and thawing of subprimals did not impact palatability ratings or WBS force values when compared to subprimals that were only refrigerated during storage. This highlights the opportunity for increased flexibility in industry for inventory control purposes because freezing and thawing subprimals did not negatively impact consumer acceptability or shear force values.

4.2. 14- versus 35-day aging

Table 3 contains weights, steak temperatures, cook loss, grill temperature, and cook durations for all sensory and WBS force steaks that were cut from subprimals assigned to the 14- or 35-day aging treatments. There were no sensory panel ratings or WBS force value differences ($P > 0.05$) between the refrigerated versus frozen aging treatments (Table 4). The average WBS force values for steaks from both 14- and 35-day aging treatments were within the “very tender” category (Belew et al., 2003).

Table 3. Paired t-tests for weights, steak temperatures, cook loss, grill temperature, and cook duration of sensory and Warner-Bratzler shear force steaks from subprimals that were aged for 14- versus 35 days.

Treatment[a]	*n*[b]	Raw weight (g)	Raw internal temperature (°C)	Cooked weight (g)	Cooked internal temperature (°C)	Cook loss (%)	Grill surface temperature (°C)	Cook duration (min)
14 d	10	169.6	13.6	128.6	70.1	24.1	176.5	16.9
35 d	10	166.0	13.2	124.9	70.1	24.8	176.6	17.1
SE		4.60	0.35	3.40	0.04	0.92	0.24	0.66
Prob > t		0.7782	0.8637	0.8542	0.3484	0.2242	0.2700	0.2901

[a] Treatment: 14 d = top sirloin butts were aged for 14 days under refrigeration before cutting into steaks; 35 d = top sirloin butts were aged for 35 days under refrigeration before cutting into steaks.
[b] Number of subprimals evaluated.

Table 4. Paired t-tests for sensory panel ratings and WBS force values for steaks from subprimals that were aged for 14- versus 35 days.

Treatment[a]	*n*[b]	Sensory panel ratings[c] Overall like/dislike	Tenderness like/dislike	Flavor like/dislike	Juiciness like/dislike	Warner-Bratzler shear force (N)
14 d	10	6.0	5.6	6.3	5.6	30.7
35 d	10	6.1	6.0	6.1	5.9	27.5
SE		0.25	0.29	0.20	0.28	1.81
Prob > t		0.6321	0.1868	0.3795	0.2948	0.1215

[a] Treatment: 14 d = top sirloin butts were aged for 14 days under refrigeration before cutting into steaks; 35 d = top sirloin butts were aged for 35 days under refrigeration before cutting into steaks.
[b] Number of subprimals per treatment.
[c] Sensory panel ratings: 9 = like extremely; 1 = dislike extremely.

Savell, McKeith, Murphey, Smith, and Carpenter (1982) reported that the most effective way to decrease WBS force values was not to rely on aging alone, but to combine blade tenderization, electrical stimulation, and an 18-day aging period. Our study aimed to determine if aging alone could alter perception of palatability and tenderness in top sirloin steaks. This treatment showed no significant differences in either subjective nor objective measurements of tenderness. There were also no differences between the two treatments when evaluating in consumer preferences for factors such as juiciness, flavor, or overall liking. Harris et al. (1992) found that although there were overall improvements in panel tenderness ratings after aging top sirloins for 28 days, WBS force values showed no significant decreases up to 35 days of aging. The lack of improvement in tenderness for top sirloins solely receiving an aging treatment has been attributed to the higher content of connective tissue in the sirloin that does not degrade during aging (Harris et al., 1992). Colle et al. (2015) reported no differences in soluble nor insoluble collagen in the sirloin during aging and attributed any likely change in tenderness to proteolytic systems. Findings of this previous study recommend that the “GM be aged for 42 days to optimize consumer perception of tenderness,” having found the highest consumer ratings of tenderness at this point (Colle et al., 2015).

It is clear from the present study that up to 35 days of aging does not result in improved palatability or WBS force values of the top sirloin when compared to those subprimals aged for the traditional 14 days. Because the top sirloin does not respond to aging like other rib and loin cuts, most purveyors employ extended-aging times as a way to ensure tenderness. Based on these findings, there is no benefit to extending the aging periods for the top sirloin, thus providing the industry with potential evidence to decrease storage times and expedite shipping to increase product availability.

4.3. Consumer data

Consumer panelists’ demographic and consumption pattern information can be found in Tables 5 and 6, respectively. The division of males to females was nearly even, with age ranges being most concentrated from 21 to 35 years old. This is representative of the large college demographic of College Station, TX, as seen again in the reported working status category with most participants either working part-time or enrolled as a student. Most consumers surveyed were white, with a household income of $100,000 or less, had no dietary restrictions, and were not closely related to the food industry by employment.

All consumers participating in this panel consumed meat, most often beef or chicken. Consumers were found to frequently consume beef three or more times a week, with most consuming beef at home twice per week and in a restaurant setting once per week. Those surveyed in this study preferred either a medium-rare or medium-well degree of doneness, and most often purchased traditional beef.

Table 5. Demographic summary of consumer panelists (n = 160)

Item	n^a	%
Gender		
Male	70	44
Female	90	56
Age		
20 years or younger	8	5
21 - 25 years	49	31
26 - 35 years	43	27
36 - 45 years	15	9
46 - 55 years	17	11
56 - 65 years	18	11
66 years and older	10	6
Working status		
Not employed	13	5
Part-time	76	48
Full-time	29	18
Student	57	23
Annual household income		
$100,000 or more	53	33
$75,000 - 99,999	29	18
$50,000 - 74,999	20	13
$25,001 - 49,999	23	14
Below $25,000	35	22
Dietary restrictions		
No	151	94
Yes	9	6
Self/Immediate family works for a food company		
No	158	99
Yes	2	1
Ethnic background		
White	133	83
Hispanic	11	7
Asian or Pacific Islander	6	4
Black	5	3
Other	3	2

[a] No. of responses

Table 6. Consumer panelists' consumption patterns (*n* = 160)

Item	*n*[a]	%
Meat consumption		
Yes	160	100
Type of meat consumed		
Beef	160	100
Chicken	159	99
Fish	155	97
Pork	139	93
Frequency of beef consumption		
Daily	14	9
Five or more times per week	35	22
Three or more times per week	71	44
Once per week/weekly	34	21
Once every two weeks	4	3
Less than once every two weeks	2	1
Frequency of beef consumed at home per week		
0	9	6
1	37	23
2	56	35
3	35	15
4	17	11
5	3	2
5+	3	2
Frequency of beef consumed at restaurant per week		
0	8	5
1	64	40
2	48	30
3	21	13
4	10	6
5	5	3
5+	3	2
Preferred degree of doneness		
Rare	6	4
Medium rare	48	30
Medium	3	2
Medium well	72	45
Well done	38	24
Type of beef purchased		
Aged	14	9
Grass-fed	18	11
Organic	14	9
Traditional	140	88

[a] No. of responses

4. CONCLUSIONS

Today's beef is inherently more tender when compared to that from the past. As such, the key questions of whether extended postmortem aging times or freezing during the aging period were necessary to result in improved palatability or WBS force values were answered. This study showed that longer aging periods (e.g., up to 35 days) are not needed for top sirloin butts, as shorter aging periods (e.g., 14 days) produced steaks of comparable sensory and WBS force characteristics. These findings allow purveyors flexibility in utilizing shorter product storage periods without sacrificing meat tenderness or quality.

Though additional research is needed to determine the exact impacts of freezing of meat in regard to enhancement of tenderness, this work showed no objective or subjective differences in comparing beef aged under refrigerated versus frozen conditions. Freezing and thawing of top sirloin butts compared to only aging them under refrigeration achieved similar and interchangeable palatability characteristics between steaks. These findings offer purveyors, retail, and foodservice establishments options in how top sirloin butts are handled before cutting into steaks, alleviating the concern of detrimental consumer perceptions due to freezing.

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